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Produced by the NASA Center for Aerospace Information (CASI)

CAL-1267

STATUS REPORT

NASA GRANT NGR 33-008-102

TITLE OF RESEARCH:

X-Ray Astronomy

PERIOD:

January 1, 1974 — December 31, 1974

PREPARED FOR:

National Aeronautics and Space Administration
Physics and Astronomy Programs
Office of Space Science
Washington, D. C. 20546

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JULY 1975

(NASA-CR-142981) X-RAY ASTRONOMY Status Report, 1 Jan. - 31 Dec. 1974 (Columbia Univ.) 33 p HC $3.75 CSCL 03A
N75-26941
Unclas
G3/89 26625

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CONTENTS

I. DESCRIPTION OF RESEARCH

A. *Observations of the Lunar Occultation of the Crab Nebula (NASA Rockets 13.107-UG and 26.030-UG)*

A recent series of lunar occultations of the Crab Nebula has provided a unique opportunity to determine the spatial distribution of the X-ray emitting region. Previous measurements of the X-ray structure have been made by using both lunar occultations and modulation collimators, but they have been limited in accuracy by counting statistics and have been over a limited energy range The U. S. Naval Research Laboratory (Bowyer *et al.*, 1964) observed the 7 July 1964 occultation using sounding rocket-borne detectors sensitive between 1–6 keV and found that the X-ray source was extended with a total angular width of about 1′. In 1966, a modulation collimator was used to determine the dimensions of the X-ray emitting volume along two orthogonal axes in the 1–6 keV range (Oda *et al.*, 1967). The results of this experiment were in agreement with the previous occultation observation and showed further that the position of the X-ray and optical centroids are within 15″ of each other. The average diameter of the X-ray volume was found to be 100″. Subsequent to these observations, interest in the X-ray emission of the Crab Nebula was reinforced by the discovery of the optical, radio, and X-ray pulsar NP 0532 and also by the positive detection of the X-ray polarization (Novick *et al.*, 1972). The pulsar very likely serves as the energy source of the Nebula, and the extended radio, optical, and X-ray continuum emissions are almost certainly due to synchrotron radiation from electrons which derive their energy from the pulsar. But details of neither the acceleration process nor the energy transport mechanism are well understood. More detailed measurements of the X-ray distribution and its possible energy dependence, together

with correlations with the associated optical and radio radiations, are required to differentiate among the various possibilities that have been proposed.

Two X-ray observations using NASA sounding rockets have been made by this laboratory during the current series of lunar occultations of the Crab Nebula (the occultations occur monthly for about one year and repeat in 11-yr cycles). The apparent motion of the lunar limb across the Nebula is ideally suited for a sounding rocket experiment as the occultation rate, typically 0.3″ sec^{-1}, is fast enough to allow observation of either immersion (disappearance) or emersion (reappearance) in a single rocket flight. Since the location of the Moon is continually changing, the position angle at contact varies from one eclipse to the next, providing a means of measuring structure along different axes. By observing the reappearance from Hawaii on 3 November 1974 (UT) and the reappearance from New Mexico on 28 December 1974 (UT), we obtained data along two axes separated by 45°. Similar large-area proportional counters were used to record each occultation. The objective was to measure the spatial structure over the widest possible energy range with enough time resolution to distinguish between effects temporally related to the pulsar and to the continuum.

The 3 November 1974 lunar occultation of the Crab Nebula was observed using an array of proportional counters carried aloft by an Aerobee-170 sounding rocket (NASA rocket 13.107-UG) launched from the Kauai Test Facility, Hawaii. Two sets of proportional counters were used, one with a 0.0025-cm thick beryllium window with an unobstructed area of 600 cm^2 and a 2.86-cm depth of xenon gas at 1 atm. The second set of detectors had 0.013-cm

beryllium windows (1400 cm^2) and a 2.54-cm depth of xenon at 1.2 atm. The field of view of the detectors was limited by rectangular cell collimators which were positioned directly over the window support bars to provide 100% transmission for incident X-rays within ±20′ of the viewing axis and a half-maximum transmission at ±3.5°. A lunar tracker was used to orient the payload viewing axis toward the limb of the Moon where the occultation occurred, and optical alignment tests performed prior to launch showed that the tracker and detector axes were coaligned to within 10′. During the flight, the tracker maintained the experiment viewing axis within a 1′ diameter jitter circle centered on the occultation point, thus ensuring that there could have been no shadowing of the X-ray source by the collimators. Any spatial or temporal variations recorded cannot be a result of rocket motion.

All of the data taken in the 3 November 1974 observation were obtained by telemetry as no attempt was made to recover the apparatus from the ocean. In-flight calibration of the detectors was accomplished before and after the observation using ^{55}Fe radioactive sources mounted in the experiment door. Each event which exceeded a lower-level threshold and passed rise-time and anticoincidence tests was examined for pulse height and time of occurrence, and digitally encoded for telemetry. A 16-channel pulse-height analyzer allowed an energy resolution of about 1 keV, and the rocket telemetry system sampling rate provided 50-μsec time resolution. The data were divided between two separate telemetry systems. Due to an apparent loose connection on one of the antenna cables, data from one of the links were excessively noisy, resulting in a partial loss of pulse-height and timing information. Postflight reconstruction procedures have been used to filter the noise,

and comparison of the same data received at different ground stations has enabled us further to reduce the loss.

The 28 December 1974 (UT) lunar occultation of the Crab Nebula was observed with an array of proportional counters carried aloft by an Aerobee-200 sounding rocket (NASA rocket 26.030-UG) launched from the White Sands Missile Range, New Mexico. The instrumentation consisted of a set of xenon-filled, sealed proportional counters and a set of flow counters with thin plastic windows to detect the low-energy X-ray flux. The sealed counters contained 2 atm of gas (90% Xe, 10% CH_4) with a depth of 3.175 cm and had 0.005-cm beryllium windows with a total unobscured area of 1302 cm^2. The flow counters were filled with P-10 gas (90% Ar, 10% CH_4), maintained at 1.2 atm by an absolute pressure regulator, and had an active volume with a depth of 3.175 cm. The windows consisted of polypropylene stretched to 1.2 μm and supported by a 72% transparent, electroformed stainless-steel mesh. All windows were coated with 50 $\mu g\ cm^{-2}$ of colloidal graphite to suppress ultra-violet transmission and provide electrical conductivity. The set of flow counters consisted of four detectors, two with one-layer plastic windows and two with two-layer windows, to provide a total unobscured area of 517 cm^2. Absolute window transparency and uniformity were measured before launch with monochromatic, low-energy X-ray beams at 0.68, 0.93, and 1.25 keV, and the overall gain and resolution were monitored during the ascent and descent of the flight with radioactive calibration sources mounted in the payload door. The system gain remained constant to within 5%. The fields of view of all detectors were limited by collimators as described above, and the possibility of spurious counts in the low-energy detectors due to electrons was further reduced by including deflection magnets between

the collimator blades. The rocket attitude was maintained within a 1′-diameter jitter circle by the lunar tracker for the duration of the observation.

Launch times were selected in accordance with calculations provided by Dr. T. Van Flandern of the U. S. Naval Observatory for the prescribed trajectories. NASA rocket 13.107-UG was launched at $11^h\ 57^m\ 53^s$ UT on 3 November 1974 along a westerly trajectory and tracked by several radars to provide an absolute position accuracy of ±100 m in each coordinate at 0.1-sec intervals. Since the occultation rate is not uniform, but decreases as the rocket loses altitude, the launch was timed to initiate observation with the lunar limb more than 90″ west of the pulsar and for reappearance of the pulsar to occur slightly after apogee. The actual trajectory was somewhat lower and more elongated than planned, resulting in a later pulsar reappearance and less observation time of the eastern half of the Nebula. The observed time of pulsar reappearance and that calculated after the flight by Dr. Van Flandern on the basis of the radar data agreed to within 1 sec (0.3″), affording us with a reliable estimate of the location of the lunar limb with respect to the pulsar throughout the flight.

NASA rocket 26.030-UG was launched at $06^h\ 14^m\ 30^s$ UT on 28 December 1974 along a northerly trajectory. Reappearance was selected to provide a view of as much of the Nebula as possible in the limited time and also to maximize the angle between scans in the two flights. Reappearance of the pulsar was almost coincident with apogee at a position angle of 300°.

Usable data were obtained in the 3 November 1974 observation at a position angle of 255° for pulsar-limb separations from -100″ to +7.5″ and in the 28 December 1974 observation at a position angle of 300° for pulsar-limb angles from -62″ to +62″ (negative angles are used to indicate the

pulsar lying behind the limb). In Figures 1–4 are shown the raw data expressed as counting rate versus distance of the lunar limb from the pulsar. Analysis of the data and interpretation of the results will be presented in a subsequent report.

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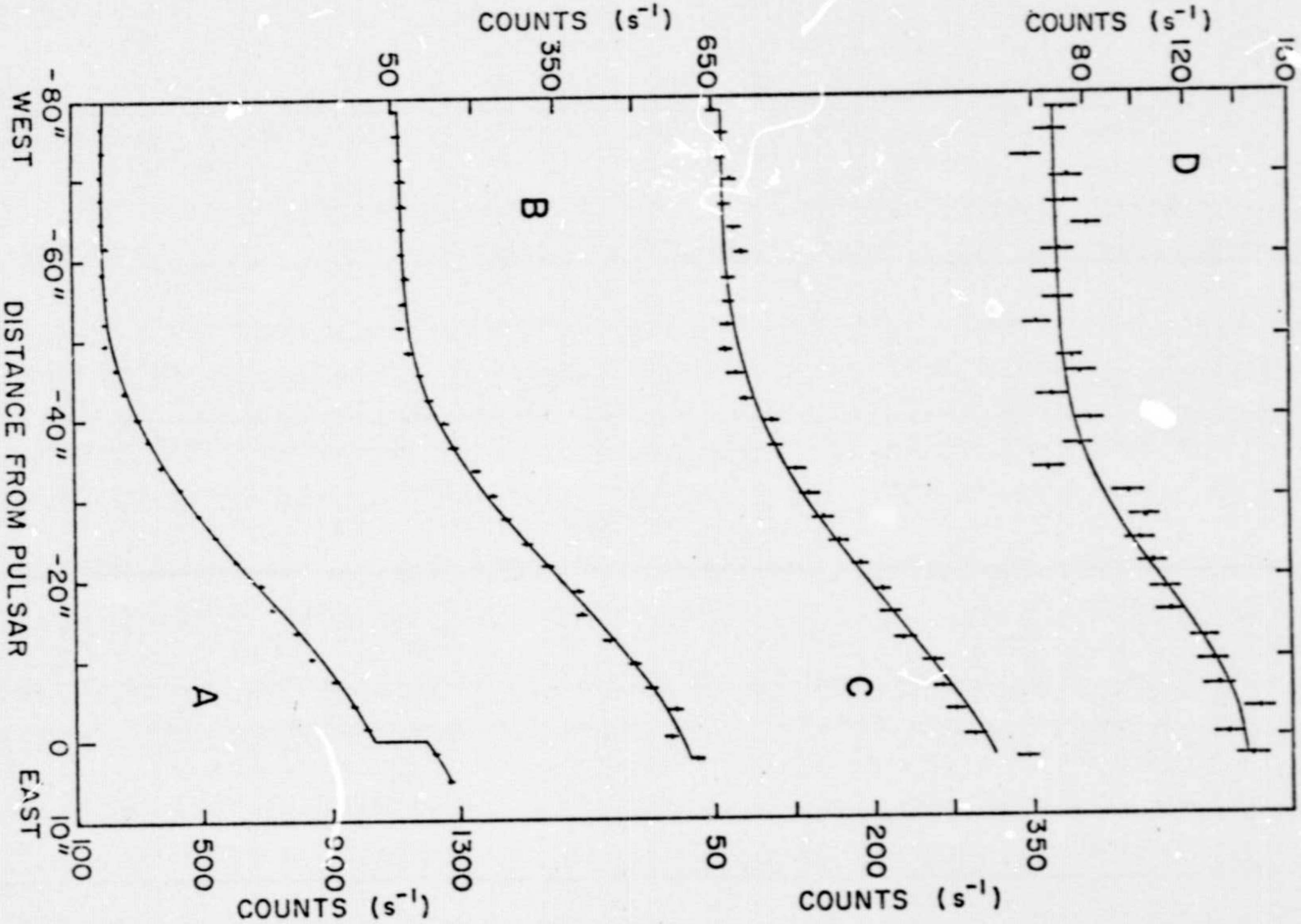

FIG. 1. — 3 November 1974 observation. Curve A shows the total 1.5—17.5 keV X-ray counting rate (detector set 1) in 3″ bins as a function of pulsar-limb separation at a position angle of 255° for all time phases. The counting rates in the nonpulsed phase (extending from 16.8—29.9 msec after the peak of the primary pulse) are given for three energy bands: Curve B for 1.5—4.7 keV, C for 4.7—10.2 keV, and D for 10.2—17.5 keV. Error bars are ±1σ, derived from counting statistics. The lines drawn through the data are the integral curves obtained from the best-fitting Gaussian distribution functions.

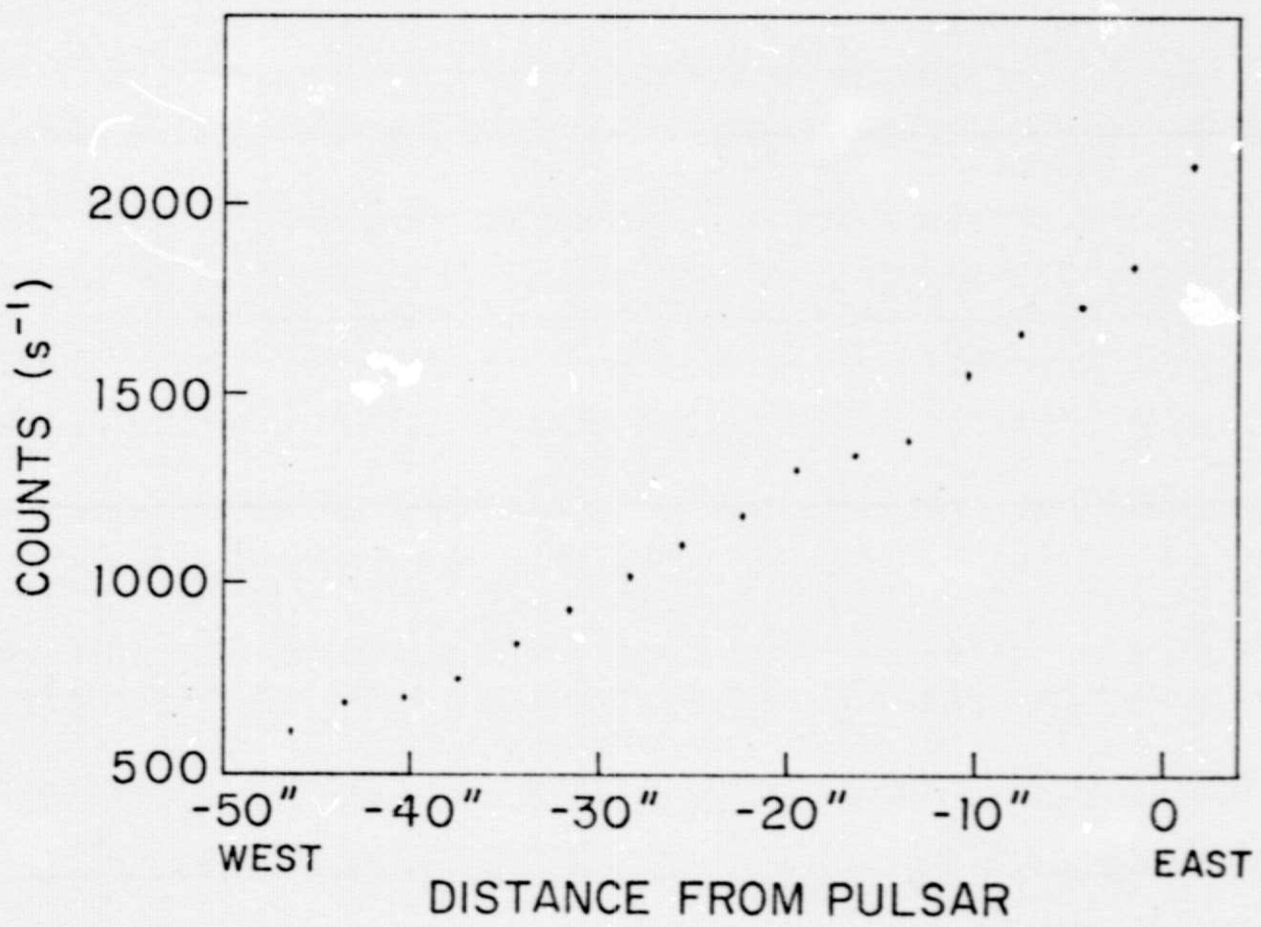

FIG. 2. — 3 November 1974 observation. The total 2.0–17.5 keV X-ray counting rate (detector set 2) in 3″ bins as a function of pulsar-limb separation at a position angle of 255° for all time phases. Error bars are ±1σ, derived from counting statistics.

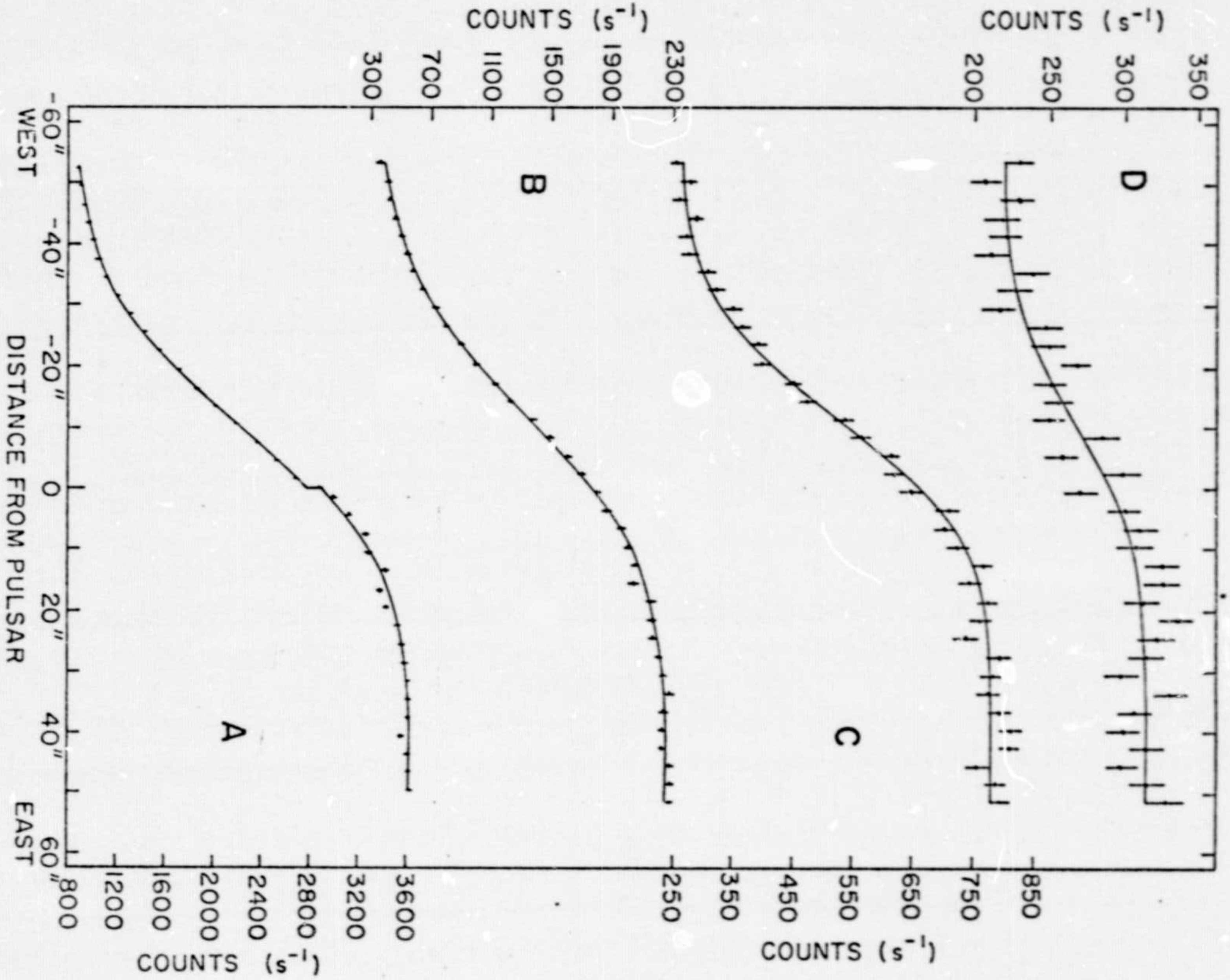

FIG. 3. — 28 December 1974 observation. Curve A shows the total 1.6—23 keV X-ray counting rate (detector set 1) in 3″ bins as a function of pulsar-limb separation at a position angle of 300° for all time phases. The counting rates in the nonpulsed phase (extending from 16.8—29.9 msec after the peak of the primary pulse) are given for three energy bands: Curve B for 1.6—6.7 keV, C for 6.7—15.2 keV, and D for 15.2—23 keV. Error bars are $\pm 1\sigma$, derived from counting statistics. The lines drawn through the data are the integral curves obtained from the best-fitting Gaussian distribution functions.

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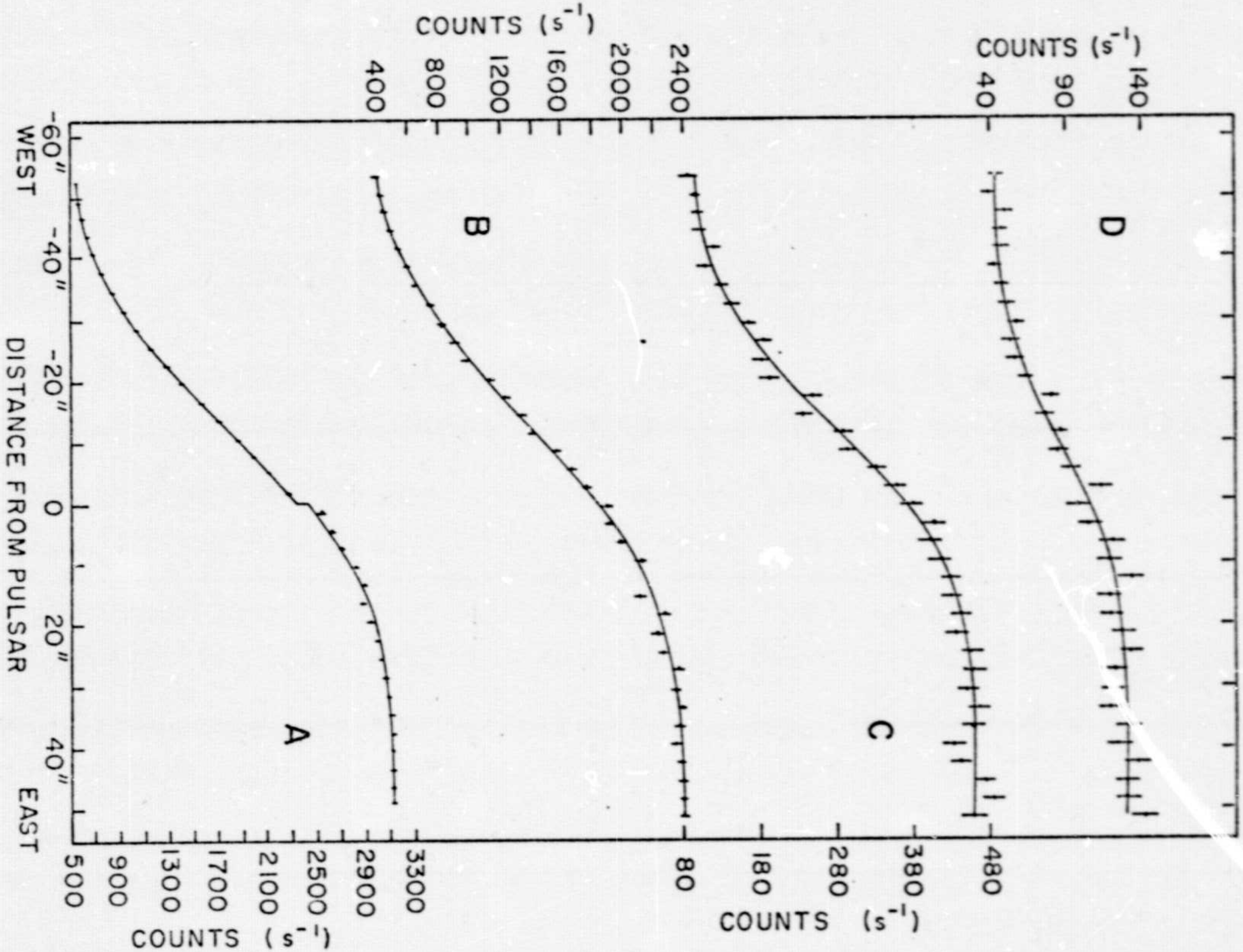

FIG. 4. — 28 December 1974 observation. Same as Fig. 3 but for detector set 2. Curve A is for the 0.6—10.0 keV data. In the nonpulsed phase the energy ranges are: Curve B for 0.6—3.5 keV, C for 3.5—6.3 keV, and D for 6.3—10.0 keV.

B. Low-Energy X-Ray Emission from the Cygnus Loop

(NASA Rocket 13.087-UG)

During this reporting period we have analyzed the data on the X-ray emission of the Cygnus Loop obtained with a one-dimensional Kirkpatrick-Baez X-ray telescope and proportional counters in the flight of NASA rocket 13.087-UG on 2 July 1973 at 1:45 a.m. MST from the White Sands Missile Range. The telescope's field of view was $1'' \times 9°$ (FWHM), and its spatial resolution was ~2′ in the narrow direction. X-rays reflected by the telescope were detected by an 11-element multiwire, gas-flow proportional counter, each element subtending 6′ in the focal plane. The instrument is sensitive in the energy range from 0.3–2.0 keV. A detailed description of the instrument is given in Helava *et al.* (1975).

The Cygnus Loop was observed in two orthogonal scans of 90-sec duration. With the aid of a star tracker and rate-integrating gyroscopes, we achieved an extremely accurate attitude control program necessary to accomplish our objective of mapping this extended X-ray source. As reported previously, the flight was only partially successful in that we lost about 30% of the data because of radio-frequency interference, and an unexpectedly hard landing resulted in more severe damage to the instruments than was expected. Despite the loss of data, a large amount of useful information was obtained during the flight.

To date our efforts have concentrated on the search for the presence of a point source of X-rays at the center of the Cygnus Loop. The very good angular resolution of the instrument together with its large effective area meant that if such an object existed, the experiment would be more sensitive to its presence than any previously flown experiment. The results of our

analysis led to an upper limit to the presence of a point source at the center of the Cygnus Loop of 2.9% (at the 99.9% confidence level) of the total emission from 400–850 eV. This upper limit is sufficiently severe to rule out evidence for the presence of a point source obtained by Rappaport *et al.* (1973) with an instrument of poorer angular resolution. Our results have been published in *Astrophysical Journal (Letters)* (Weisskopf *et al.*, 1974).

In addition to a search for a compact central object, we have also examined the energy spectrum of the flux from the supernova remnant. Our results are shown in Figure 5, and a comparison with previous observations is listed in Table 1. Although several groups have been able to fit both thermal bremsstrahlung-type spectra and synchrotron-type spectra to their data, the general consensus is that the Cygnus Loop X-ray emissions are primarily due to a thermal process since these spectra have yielded better fits to the data. For the Cygnus Loop viewed as a whole, these observations indicate a temperature of about $(2.5 \pm 0.5) \times 10^6$ °K and a hydrogen column density of $(0.05 \pm 0.02) \times 10^{22}$ H atoms cm^{-2}.

Heiles (1964) and Shklovskii (1968) show that at a temperature of $(2–4) \times 10^6$ °K strong emission should be observed at the ionized oxygen lines. These lines cluster about 0.65 keV. Gorenstein *et al.* (1971) required 30% line emission at 0.65 keV to obtain a suitable fit of an exponential spectrum to their data. Their instrument, however, had a strong absorption edge near 0.65 keV due to the Kanigen (TM) coating of their focusing collector. Thus the detection of the line was rather uncertain. Bleeker *et al.* (1972) find that a thermal bremsstrahlung spectrum gives the best fit

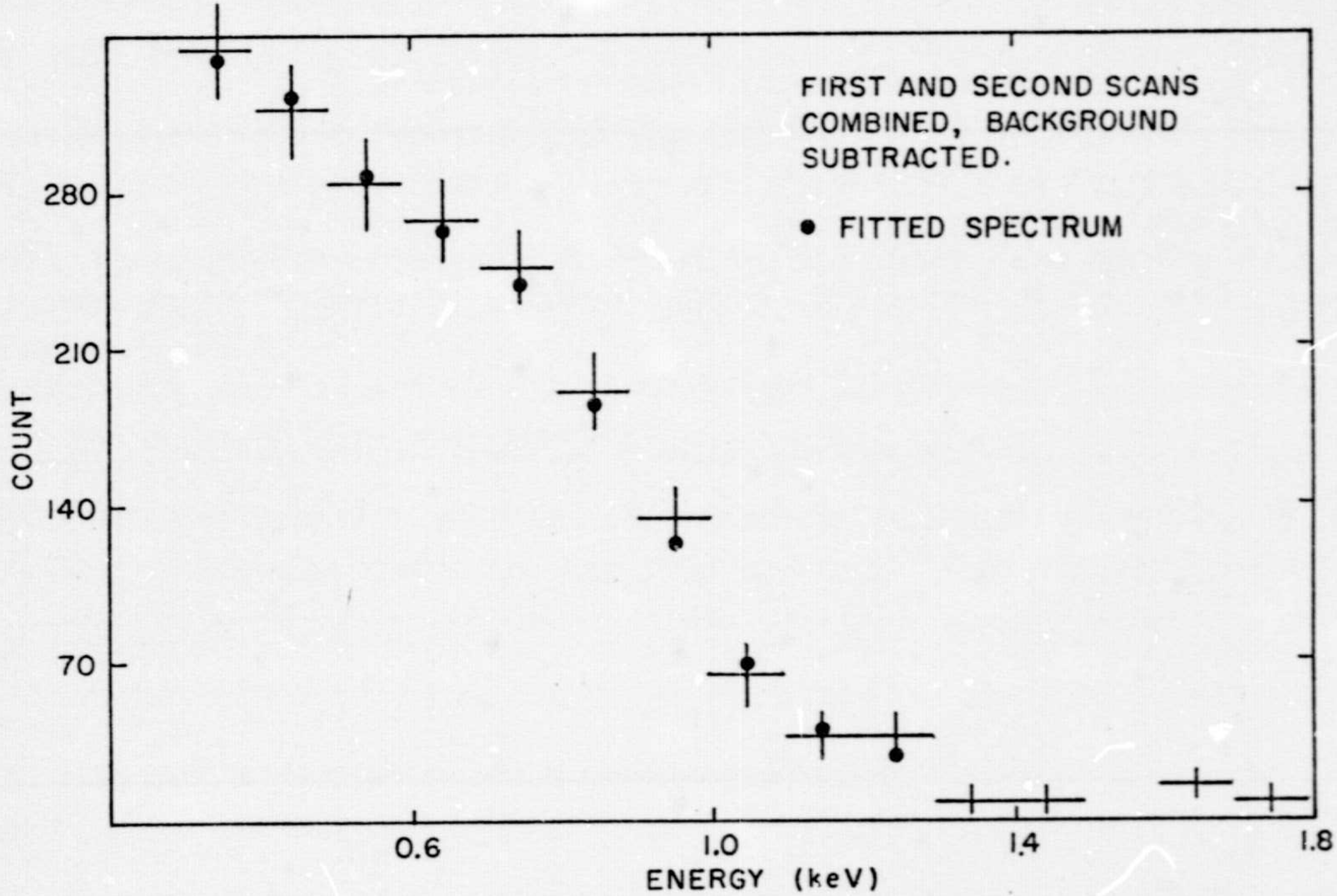

FIG. 5. — Observed spectrum of the Cygnus Loop (background subtracted). Vertical line indicates 1σ counting statistics. Horizontal line indicates pulse-height bin dimension.

TABLE 1.

Comparison of Cygnus Loop spectral observations in X-rays.

$$I(E) = \frac{A}{E} e^{-E/kT} e^{-\sigma_{BG} N_H} G(E,kT)$$

Bandwidth (keV)	A $(cm^2 \ sec)^{-1}$	kT (keV)	$N_H \times 10^{22}$	Line Emission at 0.65 keV (%)	Reference
0.2 –1.0	~150	0.370	0.026	30	Gorenstein *et al.* (1971).
0.16–6.7	140	$0.230 \pm {}^{0.02}_{0.03}$	$0.055 \pm {}^{0.02}_{0.005}$	-	Bleeker *et al.* (1972).
0.15–1	~150	$0.350 \pm {}^{0.15}_{0.15}$	$0.04 \pm {}^{0.02}_{0.02}$	-	Borken *et al.* (1972).
0.2 –1.5	$150 \pm {}^{30}_{30}$	$0.240 \pm {}^{0.02}_{0.02}$	$0.048 \pm {}^{0.002}_{0.002}$	10	Stevens *et al.* (1973).
0.15–0.85	-	$0.250 \pm {}^{0.13}_{0.13}$	$0.055 \pm {}^{0.03}_{0.03}$	-	Rappaport *et al.* (1974).
0.3 –1.3	$500 \pm {}^{300}_{200}$	$0.195 \pm {}^{0.03}_{0.03}$	$0.070 \pm {}^{0.03}_{0.02}$	0–15	Present work.

to their data but are not able to establish the presence of line emission due to poor resolution and statistics. Stevens *et al.* (1973) report that approximately 10% line emission at 0.65 keV gives an improved fit to their data. The instrument of Rappaport *et al.* (1974) also used Kanigen (TM) coating, and no report of detected line intensity is made. We were unable to establish unambiguously the presence of line emission, and we set an upper limit to the line emission at 0.65 keV of 15% of the total flux in the bandwidth from 0.3–2.0 keV.

C. *Measurement of the X-Ray Morphology of the Perseus Cluster (NASA Rocket 26.021-UG)*

During this period, a successful measurement of the spatial structure and energy dependence of the X-ray flux from the Perseus cluster of galaxies was performed with a one-dimensional, focusing X-ray telescope flown in NASA rocket 26.021-UG. The results of the experiment have been analyzed to obtain a map of the cluster in the 0.5–4.0 keV range, and various models were constructed to relate the X-ray data to the optical and radio structure associated with the cluster. The X-ray energy spectrum at different points in the cluster was also determined, providing additional insight into the emission processes which are dominant.

The apparatus used to make this measurement is described in detail elsewhere (Helava *et al.*, 1975). The instrument consisted of a set of ten gold-coated, glass surfaces laminated to a graphite-epoxy substrate and bent to a parabolic figure to provide a line image in the focal plane. The optics provided a resolution of 2′ in the focusing dimension and a 10° FWHM field of view in the orthogonal direction. The telescope was used in a previous sounding-rocket experiment to measure the spatial structure of the Cygnus Loop in July 1973 (NASA rocket 13.087-UG). After refurbishment, the plates were realigned at visible wavelengths and then calibrated at a series of X-ray energies with the large-area, parallel X-ray beam facilities at Columbia. The 2′ resolution was verified, and the energy sensitivity determined as well.

A further modification to the detector was made to improve the efficiency at higher energies, where the Perseus cluster X-ray flux is substantial. Experiments were performed to measure the effect of mixtures of xenon

and argon on counter gain and resolution. The results indicated that the addition of small amounts of xenon increased the gain without seriously degrading the resolution. Above 15% xenon, the gain began to decline, and at 20% it was equal to that of pure argon. Consequently, a mixture of 15% xenon, 75% argon, and 10% CH_4 was selected. As a result of this work, the characteristics of several different gas mixtures were determined, and these data have been analyzed and published (Wolff, 1974).

The experiment was readied for launch in winter 1974 from the White Sands Missile Range. The observing program was to acquire Algol as a reference star, and then scan slowly (at $2'' \text{ sec}^{-1}$) across the Perseus cluster parallel to the line of galaxies between the nucleus of the cluster, NGC 1275, and the radio galaxy IC 310. After three scans along this axis, the instrument was rotated 90° and held stationary for 40 sec to collect spectral data. Two scans along the second axis were made, also at $2'' \text{ sec}^{-1}$. All scans were nominally ±0.5° of the cluster center. Before reentry, the telescope was maneuvered to the Crab Nebula, which was scanned at $6' \text{ sec}^{-1}$ to measure the instrument response to a compact source with a well-established X-ray spectrum.

The experiment was successfully performed on 8 February 1974, and all objectives were met. The payload and aspect photographs were recovered in adequate condition, and with some refurbishment the equipment could be used again. The initial efforts to reduce the data were directed toward obtaining the spatial structure. Using the aspect photographs, which were interpreted with a microdensitometer and ruling engine to an accuracy of 1′, we superimposed the data from the scans to produce a composite result along

each of the two axes (designated E–W along the line of galaxies and N–S in the perpendicular direction). Background was subtracted, and corrections were made for the lens efficiency and exposure. The results, shown in Figures 6 and 7 (Wolff *et al.*, 1974), reveal a rich X-ray structure.

We note first that the cluster consists of both a pointlike source and extended emission region. The peak in the X-ray flux which appears in both scans corresponds to the location of NGC 1275, the Seyfert galaxy which dominates the radio and optical structure of the cluster. The width of the X-ray peak is different for the two scans and, in both cases, is wider than that produced by only a compact source like the Crab Nebula. The peak intensity for the N–S scan is a factor of 2 greater than the E–W scan. The X-ray emission remains significant at large angular distances from the peak and is nonzero for almost the entire extent of both scans. The flux diminishes more gradually with distance from NGC 1275 as measured along the line of galaxies than along the N–S axis.

We have interpreted these measurements in terms of models with several components, motivated by both the data available at other wavelengths and various theoretical hypotheses that have been proposed to explain the X-ray emission. The best fit between the experimental results and the models was obtained with a three-component model consisting of a point source located at NGC 1275, an isothermal sphere centered on NGC 1275, and a uniformly luminous disk viewed edgewise, aligned parallel to the line of galaxies. The motivation for the model is apparent from the asymmetry in the data: a point source is required to account for the peak observed at the location of NGC 1275, but the difference in the intensity observed in the two scans

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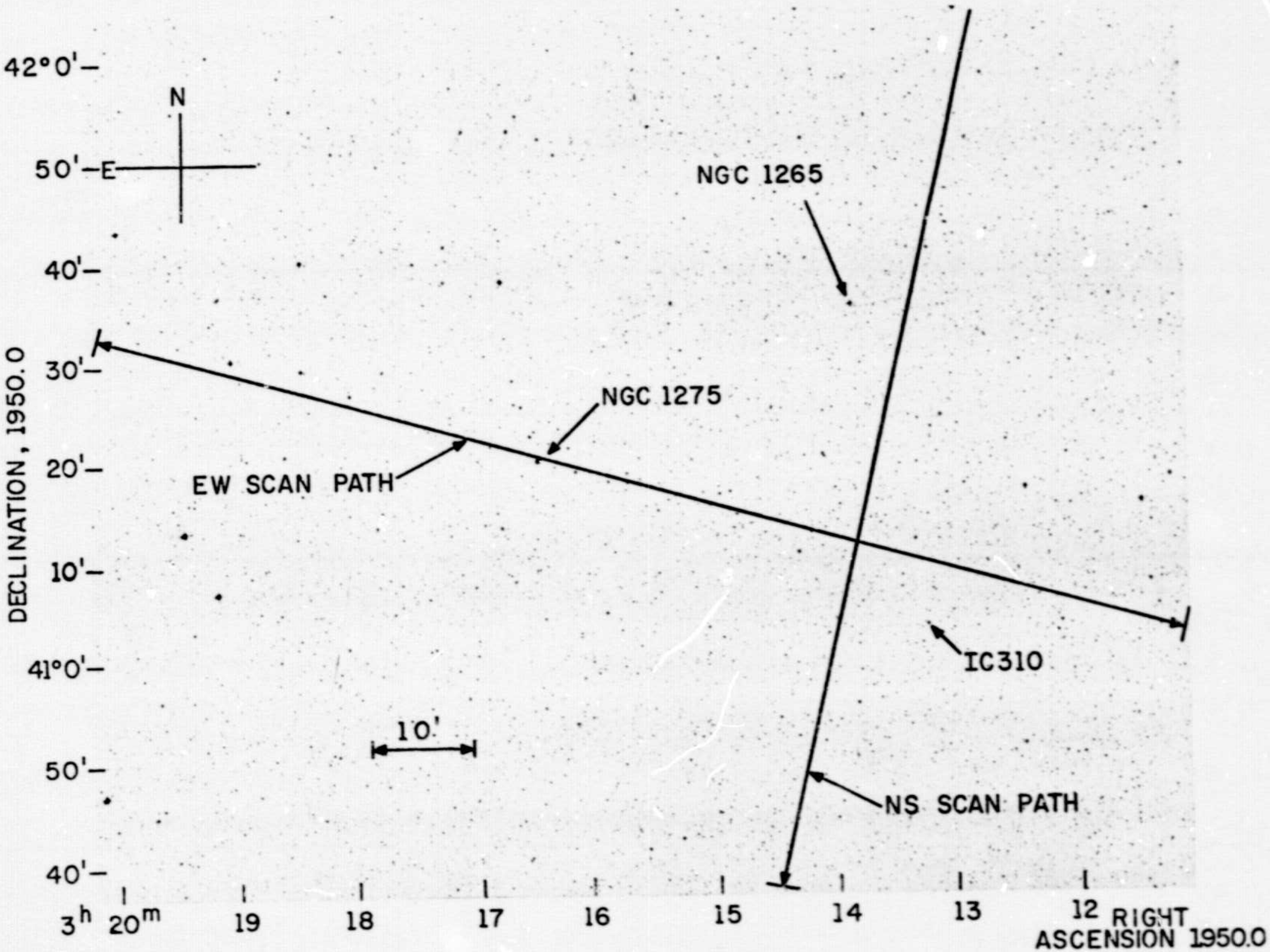

FIG. 6. — The scan paths superposed on the Palomar *Sky Survey* plate of the Perseus cluster. The lengths of the lines indicate the total extent of the scans. The nonfocusing axis of the telescope is perpendicular to the scan line in each case (Wolff *et al.*, 1974).

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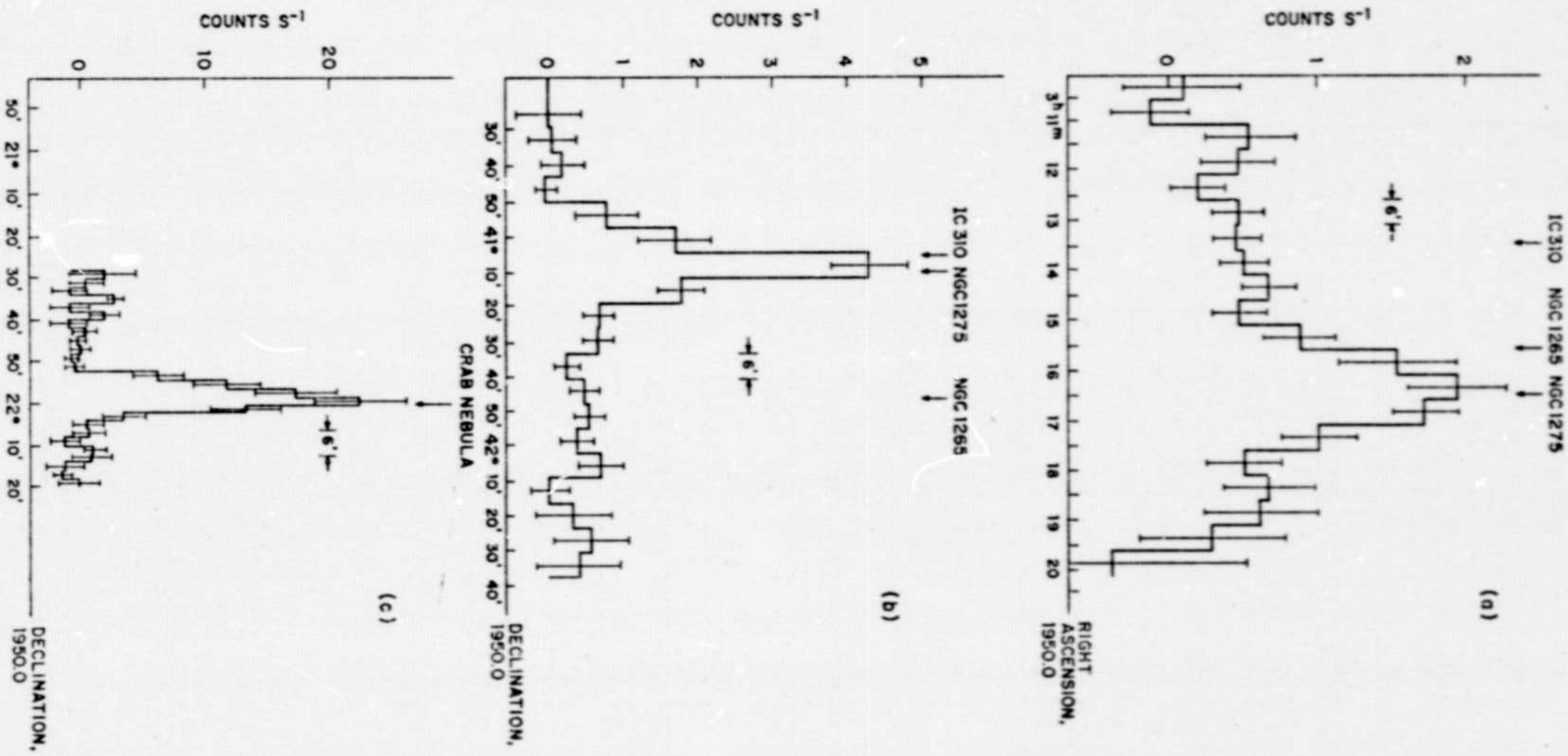

FIG. 7. — (a) Counts sec^{-1} versus angle for the E–W scans of the Perseus cluster. The data have been summed into 6′ bins and background subtracted. (b) Same as (a) but for N–S scans. (c) Counts sec^{-1} versus angle for the Crab Nebula scan. The data are summed into 2′ bins and background subtracted (Wolff *et al.*, 1974).

indicates that a substantial amount of flux must be associated with the line of galaxies, which was parallel to the nonfocusing axis of the lens in the N–S scan. Finally, the nonzero flux at large distances from NGC 1275 in both scans is evidence for a much more extended emission volume.

A multiparameter χ^2 analysis was used to fit the model to the data with the following results. The point-source intensity contributes to about 15% of the observed flux, the sphere about 50%, and the disk about 35%. The best-fitting parameters yield a sphere with radius of about 50′ and a disk with radius 120′ and thickness of 18′. The model components can be attributed to various physical processes that have been proposed to explain the phenomena associated with the cluster. The point source is clearly emission from NGC 1275, an extremely optically active Seyfert galaxy containing a compact, subarcsecond radio core and a slightly extended (2″ diameter) halo. The spherical emission volume may be due to a hot, intracluster gas which occupies the space between the galaxies in the cluster. Finally, the disk emission could be the result of local heating in the region where the galaxies are concentrated, or perhaps the sum emission of individual galaxies. This last possibility seems remote, as the observations showed that there are no other resolvable point sources in the cluster with intensity greater than 0.1 that of NGC 1275. Also, to account for the disk emission, each galaxy would need a luminosity 10^3–10^4 times greater than that usually associated with typical galaxies.

The energy spectrum of the X-ray flux was next investigated to elucidate further aspects of the different regions of the cluster. Because of the limited number of total counts, it was necessary to bin the data into two spatial categories: the region on NGC 1275, in which the field of view

of the telescope was within ±4′ of the Seyfert galaxy, and the region off NGC 1275, consisting of the extended emission volume. The initial test for spectral distinctions was to consider a hardness ratio R, defined by the relation

$$R = \frac{I(0.5\text{–}1.75\ \text{keV})}{I(1.75\text{–}4.5\ \text{keV})} \quad , \tag{1}$$

where I(0.5–1.75 keV) is the flux in the 0.5–1.75 keV range and I(1.75–4.5 keV) is the flux in the higher band. Small values of R then result when the high-energy flux is large (a hard spectrum) or the low-energy flux is small (a compact, self-absorbed source). The results of this calculation showed that $R_{\text{on NGC 1275}} = 1.26 \pm 0.15$ and $R_{\text{off NGC 1275}} = 1.75 \pm 0.18$, indicating a significant difference in the energy spectra of the two regions. The tentative interpretation is that the extended region could be characterized by an optically thin, thermal spectrum while the point source flux is better explained in terms of a power-law spectrum with a low-energy cutoff.

The spectral differences were examined in greater detail by fitting the data to power-law and thermal functions, including the effects of interstellar absorption, and varying the parameters to minimize χ^2. The results indicated that the data for the region on NGC 1275 are best characterized by a power law with an exponent of 2.2 ± 0.5, and that a substantial amount of self-absorption is also required. In terms of hydrogen column density n_H, a value of at least $2.5 \times 10^{21}\ \text{cm}^{-2}$ is required to obtain a good fit. The data from the extended region were best fitted by a thermal spectrum with T = 8 keV and $n_H \lesssim 10^{21}\ \text{cm}^{-2}$ which is in better agreement with the estimated density of interstellar matter in the direction of the Perseus cluster. Fitting the thermal emission to an isothermal sphere with radius

50′, we find a hot gas would have a total mass of about 1.44×10^{14} $M_{\odot}$, approximately a factor of 7 less than that needed to bind the cluster. The results of spatial and spectral analyses, along with more detailed interpretation, have been reported at meetings and have also been published (Wolff *et al.*, 1974; Wolff, 1975; Wolff *et al.*, 1975).

D. *Fluorescence Proportional Counter for Observation of X-Ray Spectrum of Scorpius X-1*

The recent development of high-resolution gas fluorescence proportional counters by Policarpo *et al.* (1967) opens the way for important new measurements in X-ray astronomy. These detectors have a resolution that is more than a factor of 2 better than that of conventional proportional counters. This high resolution has been obtained in energy ranges from a fraction of a kiloelectron volt to many kiloelectron volts. These detectors are potentially more valuable than solid-state silicon detectors because they exhibit good resolution and good efficiency down to the 0.25-keV band. It should be possible to produce these detectors with large area without sacrificing resolution.

The favorable resolution of these detectors suggests their use to study the continuum shape of compact X-ray sources and to search for broadened X-ray lines. As a first experiment, we propose to use an array of these detectors in a rocket flight to search for broadened Fe XXV and Fe XXVI lines in the X-ray spectrum of Sco X-1. The continuum profile between 2–10 keV will be examined for evidence of line emission and for deviations of the continuum shape from that of an optically thin plasma due to Compton-scattering processes. Although Sco X-1 has been extensively studied for the past 12 years, to date there have been no indisputable measurements of X-ray emission lines from Sco X-1 or from any other stellar X-ray source.

Despite the lack of observational evidence for X-ray line emission in the spectrum of Sco X-1, there are compelling reasons to believe that the emission process is thermal bremsstrahlung. Measurements of the X-ray spectrum in the 1–20-keV range yield data reasonably well fitted to an exponential

spectrum, and there are both optical and infrared data which substantiate this model. Detection of line emission would not only confirm the hot-plasma model for Sco X-1 but would also add considerable support to our interpretation of the observations of other X-ray sources.

To date proportional counters and crystal spectrometers have been used to search for the spectral features in the spectrum of Sco X-1 between 6–8 keV. The 15–20% energy resolution afforded by proportional counters is not sufficient for their unambiguous detection, and the electron-volt resolution and small scan range of crystal spectrometers are too narrow. An instrument with intermediate resolution of perhaps 5–10% but with large, sensitive area and extended energy range is required to detect the characteristic Comptonized emission profile.

Palmer and Braby (1974) have produced gas fluorescence proportional counters with 8.5% energy resolution at 6 keV, and we have begun a laboratory program to study these detectors. Our first effort has been directed toward reproducing the published results. We have assembled the necessary supporting equipment and gained practical experience in developing a parallel-plate gas fluorescence proportional counter.

The supporting equipment consists of a vacuum system, a gas purifier, and the necessary electronics to analyze the signal. The gas purifier is similar to the one described by Policarpo *et al.* (1967). It contains 1 lb of calcium turnings and is water-cooled at the top and at the inlet and outlet. It is heated by external heating elements which can bring the temperature of the calcium turnings to over 500°C. The temperature is regulated with two variable transformers and may be read by either a thermocouple or a thermometer. The vacuum system consists of an oil diffusion pump with a

nitrogen trap, a fore pump, and tubing and valves similar to those shown by Policarpo *et al.* (1967). The arrangement allows the detector and purifier to be evacuated for outgassing and then filled with gas.

The construction of our first detector was similar to that described by Palmer and Braby (1974). The walls are made from 58 mm i.d. laboratory glass tubing. The inside of the tubing is painted with reflective paint and a wavelength shifter. A quartz window, also coated with wavelength shifter, is located at one end, and an aluminum plate with two gas ports and a small aluminum window at the other. The parallel grids are made of 83% transparent nickel mesh. The high-voltage leads are attached to the grids on the exterior of the tube and supported with epoxy. The aluminum end plate is maintained at ground potential. The detector is assembled with Torr Seal, a low-vapor-pressure epoxy manufactured by Varian Associates, Palo Alto, California. The photomultiplier tube is coupled to the quartz window with Dow-Corning 20-057 optical coupling compound. The detector is then wrapped in black plastic electrical tape to make it light tight.

The reflective paint used is Reflector Paint NE 561, manufactured by Nuclear Enterprises, San Carlos, California. We had originally intended to use magnesium oxide as the reflector but found that it did not adhere to the surface well enough for our purposes. We tried a variety of methods of surface preparation before the magnesium oxide was smoked onto the glass, but the motion of the gas in evacuating and filling the detector washed it off in places.

The wavelength shifter, p-terphenyl, is vaporized on to a thickness of 3–4 mg cm^{-2}. Para-terphenyl was chosen since Alves (1974) has shown that it has a greater light output than the other wavelength shifters tested and has a maximum efficiency over a wide range of thicknesses.

We have attempted to operate the detector filled with argon and 3% nitrogen at 760 Torr. We have had sparking problems between the grids, a problem that Palmer (private communication) has also experienced. We hope to alleviate this problem by placing field-forming rings between the two grids.

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